OBSERVATIONS AND CLOUD-RESOLVING MODEL SIMULATIONS OF CIRRUS ANVIL SPREADING AND DECAY

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Introduction

Observations show that cirrus clouds often result from the life cycle of convective cloud systems. Machado and Rossow (1993), using satellite imagery, found that relatively thin high clouds constitute a large part of of the area covered by such systems, especially when considering the system's entire life cycle.

Schematic of the life cycle of a convective system [from Machado and Rossow (1993).]

1-km visible imagery with radar overlay showing anvil formation and spread on 16 July 2002 at half-hourly intervals during CRYSTAL-FACE. (http://angler.larc.nasa.gov/crystal/)
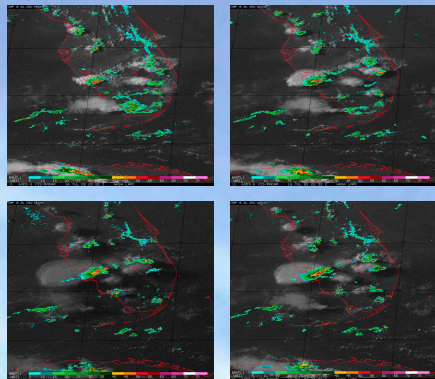

The Problem

From a GCM perspective, convectively generated cirrus anvils originate from concentrated subgrid sources. In order to more realistically represent both radiative and microphysical processes in anvil clouds in GCMs, the cloud fraction due to anvil clouds should be included by representing, in a simplified fashion, the physical processes that form, maintain, and dissipate anvil clouds. The fraction of a grid cell occupied by anvil clouds is largely determined by the history of the clouds, so that a prognostic cloud fraction parameterization is appropriate. Such an approach has been developed by Tiedtke (1993), and extended by Randall and Fowler (1999). To date, these methods have not been examined using cloud-resolving models (CRMs) or tested against observations except indirectly using global, monthly averaged datasets

The Approach

We are using the 2D University of Utah CRM to study the cirrus clouds that result from the life cycle of convective cloud systems. (1) We are performing idealized 18-h CRM simulations of the life cycle of anvil clouds to study the physical processes that determine the cloud fraction of anvil clouds. (2) We are analyzing a 29-day simulation based upon Case 3, a joint GCSS and ARM intercomparison project. (3) We are using GOES cloud products provided by Pat Minnis et al. to determine how cloud amount and ice mass are related and to compare the retrievals to the CRM simulations.
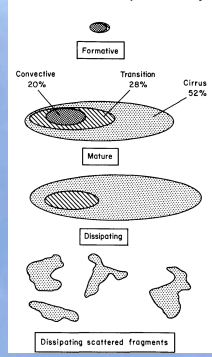
Idealized Simulations

The UU-CRM specifications included a 200 m grid size in both the horizontal and vertical directions and a spatial domain 51.2 km long and 18.2 km high. We represented the generation of cirrus anvils by detrainment from deep convection by adding (``injecting'') cloud ice in a layer between 9 to 11 km height and in a sub-region of the domain over a time period of 6 hours. The horizontally averaged rate of ice addition was 0.067 kg m^{-2} h^{-1} for most runs. We ran each simulation for a total of 18 hours.

We ran nearly 40 simulations. Results from 8 simulations are shown below.There are two major conclusions from the idealized simulations:
(1) A general diagnostic relationship between cloud fraction and IWP does not exist. However, there is a diagnostic relationship in the final decay stage. This suggests that a prognostic approach is generally required to determine cloud fraction for convectively generated cirrus.
(2) A mesoscale circulation is generated within the cirrus anvil during and for some time after the ice injection period that spreads the cloud horizontally at about 1 m/s. The circulation is generated by radiative heating within the cloud layer. As the cloud spreads due to the mesoscale circulation, the radiative heating also spreads. The result is a positive feedback that lasts as long as there is a sufficient cloud ice. This spreading mechanism has not been previously reported.

**Cloud ice plus "snow" fields at 3, 6, and 9 h for two simulations with different injection fractions.**
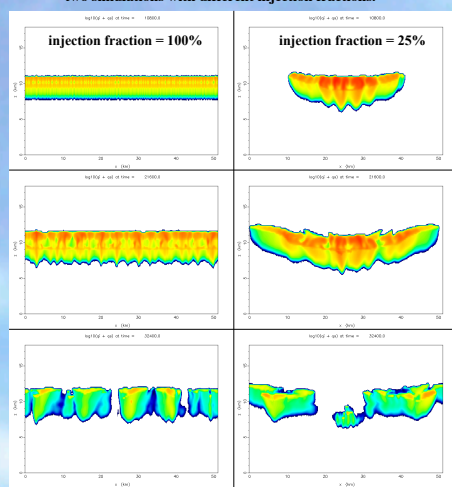
Trejectories of cloud amunt and average ice water path for simulations with different injection fractions (left) or different injection rates, injection periods, environmental humidity, etc
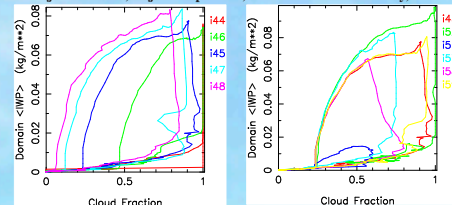

Case 3 Simulation

This simulates the cumulus convection (and attendant creation of cirrus) observed at the Southern Great Plains Cloud and Radiation Testbed site during the 29-day Summer 1997 IOP of the ARM program. As such, a rich variety of cloud property observations are readily available for comparison. The panel to the right shows sample hourly reflectivity snapshots of all hydrometeors (black is >20, color range is -60 to +20) for part of a Case 3 simulation (512 km x 16 km) with interactive radiation.
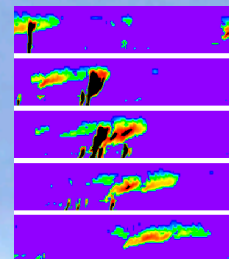
Below we compare the evolution (trajectory) of the cloud fraction and IWP in the idealized simulations (last column) to that in a full life-cycle simulation in which cirrus anvils were generated by deep convection. The evolution of cloud fraction and IWP and their correlation is essentially the same as in the idealized simulations.
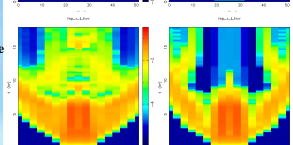

Hovmuller diagram of vertically integrated cloud ice and snow (kg/m2) for a 14-h period from the Case 3 simulation (left) and the corresponding trajectory of cloud amunt and average ice water path (right).
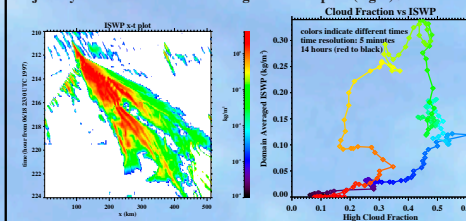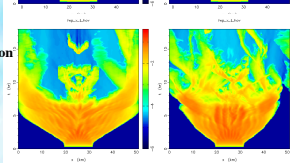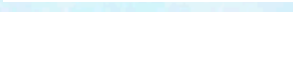

CONTROL: ice injected, no solar radiation; dx=0.2 km
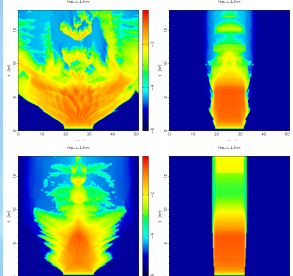
no radiative fluxes; inject water vapor, not ice

no cloud-scale motions (dx=3.2 km)

solar radiation included

no radiation

no cloud-scale or mesoscale motions

no cloud-scale motions or parameterized turbulence

**solar radiation included; radiative effects of "snow" included**

Observations

As part of our DOE ARM research, we used Minnis et al.'s pixel-level cloud products for the DOE ARM SGP site, (which are the same as those available for CRYSTAL-FACE), to provide observational insight into the relationships between cloud amount, large-scale IWP, and cloud-radiative forcing for cirrus clouds, and to provide data for model evaluation. We will analyze the corresponding CRYSTAL-FACE cloud products similarly.

Time series of large-scale OLR (clear-sky and all-sky), clear-sky fraction, and IWP for a 10-day period during Case 3 from Minnis
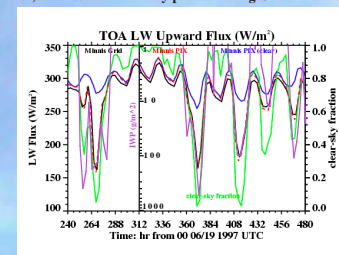
Cloud amount versus IWP for CRM (blue) and Minnis pixel-level data (red) for Case 3. The results are quite similar, and they demonstrate that there is not a general diagnostic relationship between cloud amount and IWP for cirrus clouds.
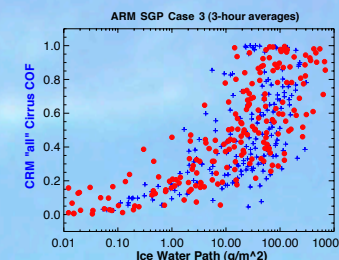
References

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Randall, D. A., and L. D. Fowler, 1999: Eauliq: The Next Generation. Atmospheric Science Paper No. 673, Colorado State University, 65 pp.

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These Hovmuller diagrams of IWP show the spread of anvil cloud for 8 idealized simulations. They show that:
• *There is no spread without radiation*, **except when vapor instead of ice is injected.**
• *Mesoscale motions are required for spreading.*
• **Cloud-scale motions and/or turbulence are NOT required for spreading.**
• *Solar radiation does not reduce the spreading.*